Comparison of satellite rainfall data with observations from gauging station networks

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Summary

Networks of ground-based hydro-meteorological observations are frequently sparse in developing countries and the situation is not improving. Part of the reason is the lack of resources available in countries which have more pressing economic and social issues. However, these are also the very countries where improved estimates of water resource availability are required. While hydrological models have the potential to provide the necessary information, without adequately accurate climate (rainfall, evaporation, etc.) input information, it is extremely difficult to establish models and generate representative water resource availability information. This paper reports on a preliminary analysis of the potential for using satellite derived rainfall data through a comparison with available gauge data for four basins in the southern Africa region. It is clear that the satellite data cannot be used directly in conjunction with historical gauge data. Specifically, the satellite data do not reflect the strong influences on precipitation of topography in some of the basins. However, the prospects of applying relatively straightforward adjustments are promising and further assessments appear to be justified.

Introduction

Within many developing countries and specifically parts of southern Africa, networks of ground-based rainfall observations have always been relatively sparse. The situation is not improving and the density of many networks is decreasing, the amount of missing data is increasing and the reliability of some of the data is becoming increasingly suspect. Part of the reason for this trend is the lack of commitment to funding hydro-meteorological gauging networks in countries that have many more immediate economic issues. However, these are the very countries where economic and social development depends, to a certain extent, on the availability of sound water resources information. Without an adequate network of river flow gauging stations, it is common practice to make use of hydrological models. However, the successful application of such models relies heavily on, inter alia, an accurate representation of basin precipitation inputs. It is increasingly evident that new approaches need to be adopted to provide these inputs as future gauge networks are unlikely to meet the requirements.

Global, or near-global, datasets of a wide range of terrestrial information derived from satellite imagery are becoming increasingly available and accessible. The type of information available includes not only relatively static characteristics, such as land cover (d’Herbès and Valentin, 1997), but also time series variations, such as temperature (Xiang and Smith, 1997), evapotranspiration (Kite and Droogers, 2000), soil moisture (Valentijn et al., 2001) and precipitation (WCRP, 1986). Many of these have the potential to fill some of the information gaps and provide input data for water resource estimation models in developing regions. However, there are several practical considerations that need to be addressed if such products are to be used successfully and with confidence:

• In many cases hydrological models already exist and have been calibrated against historical gauged data.

• Satellite data have a relatively short period of record and do not cover the various cycles of wet and dry periods frequently found in hydrological records.

• The previous two points suggest that ideally gauged and satellite data need to be used together and therefore, the relationships between the two data sources need to be quantified and clearly understood.

• The data have to be accessible to water resource practitioners in the developing countries.

• The techniques required to make effective use of the data should not be excessively complex nor difficult to understand, as the resources available for data analysis and processing are frequently limited in developing countries.

There have also been many region specific studies of the use of satellite rainfall data, several of these covering the African continent (Todd et al., 1999, Thorne et al., 2001 and Grimes and Diop, 2003). However, despite their scientific value, many of these do not satisfy the final two criteria for general application within developing countries with limited resources. This paper is therefore not concerned with the research issues associated with calibrating satellite data, but with the more or less direct use of available satellite derived information products in water resource estimation procedures. The focus of the study is on satellite precipitation data and their potential use for input to monthly time-step, rainfall-runoff simulation models applied to relatively large basins (about 10,000 km^2 and greater). The assumption is that historical gauge-based rainfall data will have been used previously as input to the models and therefore that it is important to understand the relationships between the two sources of rainfall data if they are to be used together.

Near global satellite precipitation products

There are a number of references to satellite precipitation estimation methods and products in the hydrological and meteorological literature. These include TAMSAT (Grimes et al., 1999 and Thorne et al., 2001), TOVS (Susskind et al., 1997), GPCP (Huffman et al., 1997 and Huffman et al., 2001) and PERSIANN (Hsu et al., 1999 and Sorooshian et al., 2000). The two that appear to be the most straightforward to access (via internet links) and process into readily usable information are the GPCP and PERSIANN data sets.

The GPCP (Global Precipitation Climatology Project) 1DD dataset is based on merged information from several sources:

• GPCP Geostationary Satellite Precipitation Data Centre (IR Tb histograms),

• GPCP Merge Development Centre (GPCP SG Merged precipitation estimate and GPROF 6.0 SSM/I fractional occurrence), and

• GSFC Satellite Data Utilization Office (TOVS precipitation estimates – (Huffman et al., 2001)).

The temporal resolution is 1 day, the spatial resolution 1° and the period of record of available data is currently October 1996 to January 2005. Various groups prepare precipitation estimates from individual data sources, while the GMDC (GPCP Merge Development Centre at the NASA Goddard Space Flight Centre) are tasked with combining these into the final product. Each data file (7.4 MB) on the website (www1.ncdc.noaa.gov/pub/data/gpcp/1dd/data/) consists of 1 month of data for the entire globe and it is a relatively simple matter to develop a computer program to extract the data required for a specific region.

The PERSIANN (Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks) datasets have a temporal resolution of 6 h, a spatial resolution of 0.25° and covers regions between 50°N and 50°S (Hsu et al., 1999). The estimates are based on grid infrared images from geosynchronous satellites (GOES-8, GOES-9/10, GMS-5, Metsat-6 and Metsat-7) and TRMM TMI instantaneous rain from NASA. The 6 h data files (2 MB) for complete months can be downloaded (between 112 and 124 individual files zipped) from the University of California, Irvine website (hydis8.eng.uci.edu/persiann) and, as with the GPCP data, are straightforward to process and extract the data required. An inspection of the individual 6 h data indicates that there are missing data in most of the months for the southern Africa regions of interest. However, they are frequently single 6 h periods, not biased to any specific time of the day or season of the year and result in less than 5% of the accumulated days being missing. The assumption has been made that they will not substantially affect accumulated monthly totals. The PERSIANN data are available for March 2000 to December 2004.

For both satellite data sources, the amount of time to download the complete datasets is quite substantial and at commercial internet fee rates would be very expensive. It does not seem to be currently possible to select a specific region on the websites and download only the data for a specific region of interest.

Test basins

The spatial resolution of the satellite data is relatively coarse, the implication being that they are most appropriate for water resource assessments in relatively large basins or sub-basins. The Institute for Water Research (IWR) has been involved in hydrological modelling studies and water resource assessments in several parts of southern Africa. Four basins have the potential to provide suitable test cases for comparing the satellite data with other sources of rainfall information. The Okavango River basin (530,000 km^2 in Angola, Botswana and Namibia) has been the subject of several cooperative research programmes, largely because of the perceived sensitivity of the Okavango Delta to upstream water resource developments. The IWR has applied a revised version of the monthly time-step Pitman model (Hughes, 2004) to the whole basin (Andersson et al., 2003). The main problem in this basin is that the dominant runoff-producing area is within Angola, while gauged rainfall and river flow observations ceased in that country during the early 1970s. As part of the WERRD (Water and Ecosystem Resources in Regional Development – www.okavangochallenge.com) project, the University of Sussex developed satellite rainfall estimates for 1991–1997 using data from TRMM (Tropical Rainfall Measuring Mission), SSM/I (Special Sensor Microwave Imager) and METEOSAT. Wilk et al. (2006) discusses some of the issues that have already been raised in using these data together with the historical rainfall data in the river flow simulation studies and these will be further referred to below.

The Kafue Basin (156,995 km^2) in Zambia is one of the major tributaries of the Zambezi River and plays a major role in the economy of the country (Mwelwa, 2005). Water from within the basin is used for domestic, industrial and agricultural purposes, while the Kafue Gorge Reservoir, with a hydropower capacity of 450 MW, is located in the lower part of the basin. The status of the rainfall and river flow gauging network is probably better than many parts of southern Africa, but even so there were less than 10 rainfall measuring stations operational in 2000 (Mwelwa, 2005). Rainfall in both the Kafue and Okavango basins are dominated by the effects of the Inter-tropical Convergence Zone and the zone of high pressure, anticyclonic cells to the south. The north–south movement of these two systems during the year leads to a strongly seasonal rainfall regime with the majority of the rain falling between October and April.

The Thukela River basin (29,046 km^2) in Kwa-Zulu Natal province of South Africa is an area where future water resource planning is very dependent on accurate representation of spatial variations in runoff generation. The basin also experiences a summer rainfall season with dry winters. The Drakensberg mountains form the western margins of the basin and result in steep, topographically controlled, rainfall gradients.

The Kat River basin (1715 km^2) in the Eastern Cape province of South Africa is smaller than would normally be considered given the spatial resolution of the satellite rainfall data. However, it is currently the subject of a project designed to establish a community driven water management plan and despite having a number of historically active rainfall measuring stations, the present day monitoring situation is relatively poor. The seasonal rainfall regime is quite complex, being affected by frontal systems, convective storms, advection from the Indian Ocean, as well as topographic controls. It is therefore, an area where satellite derived rainfall data would not be expected to provide satisfactory information.

Methods of comparison

The eventual objective is to be able to use a combination of historical gauge and satellite derived rainfall data as inputs to hydrological models. In that regard, perhaps the best approach for assessing the satellite rainfall data would be to calibrate the model using historical gauge data and then apply the model using the satellite data. However, simpler and quicker preliminary analyses have been undertaken and are based on pair-wise comparisons of the gauge data with the satellite data (and in some cases comparisons between gauges in close proximity and between the sources of satellite data). All of the comparisons are based on monthly rainfall totals, as the data are intended for use with monthly time-step hydrological models. The comparisons are based on visual interpretations of the time series of monthly rainfalls, as well as simple statistics (R^2 and slope) of the best fit linear regression line between the time series pairs. No further statistical measures of fit have been used during this phase of the study, although it is recognized that additional measures may be useful prior to the use of the data within a hydrological model.

In some cases, the overlaps between the gauge data and the PERSIANN satellite data are not sufficiently long to allow meaningful comparisons. In such cases, the relationships between the gauge and PERSIANN data are inferred from relationships between the gauge and GPCP data and between the GPCP and PERSIANN data. The comparisons are based on single 1° × 1° grid squares extracted from the GPCP data, the equivalent 16 0.25° grid squares of the PERSIANN data (using the numbering system indicated in Fig. 1) and any gauge data that are available within the same area.

Lat / Long	X.125	X.375	X.625	X.875
Y.125	1	5	9	13
Y.375	2	6	10	14
Y.625	3	7	11	15
Y.875	4	8	12	16

Figure 1. Grid numbering system for the PERSIANN 0.25° grid squares within a 1° × 1° area (latitude *X* to *X* + 1, longitude *Y* to *Y* + 1).

It is recognized that the satellite data represent areal rainfall, while the gauge data represent point rainfall and that this point needs to be taken into consideration in making the comparisons. At this stage of the study no attempts have been made to estimate areal averages from the gauge data. In most cases, there are too few gauges with data that overlap the satellite data period and the uncertainties associated with such estimates could potentially bias the results of this initial investigation.

Results

Kafue River, Zambia

A total of 17 1° grids cover the whole of the Kafue River basin (Fig. 2) and there are (or have been) a number of raingauges operational within the basin. However, data for many of these are not available for the periods covered by the satellite data. Data for three grid squares (28.5E, 12.5S; 24.5E, 14.5S; 27.5E; 16.5S) were extracted from the GCPC database, while the raingauge data were obtained through the Zambian Electricity Supply Co. (ZESCO; Mwelwa, pers. comm.). Table 1 indicates that data for two gauges (4100 and 4375) were available for the northern most grid point, while data for a single gauge were available for the other two grid squares (6210 and 5350). Table 1 indicates that the mean annual rainfall (MAP) varies from over 1300 mm in the north, to less than 900 mm in the south. In contrast, the GPCP MAPs vary from 900 to 800 mm, while the PERSIANN vary from 1300 to 1050 mm. Figure 3 and Figure 4 illustrate the results of the comparisons for the northern grid point. Despite their proximity to each other (65 km), the recorded rainfall at the two stations is not very highly correlated (R^2 = 0.78), suggesting that areal rainfall time series, generated from the point gauge data, would have fewer extremes than the gauge lines in Fig. 3. The GPCP data tend to under-estimate both gauge rainfalls quite substantially (regression equation slopes of 0.63 and 0.74), although in some years the correspondence with gauge 4100 is very good. In general terms, there are not substantial differences between the PERSIANN data within the 1° grid, however, there are extreme cases during the peak wet season (a difference of over 100 mm in January 2004). The correlations between the gauge and satellite data are similar for GPCP and PERSIANN (Table 1), however, the latter appear to be closer to the gauge values (i.e., less systematic difference). Fig. 3 suggests that substantial differences occur in the relationships between the satellite and gauge rainfall between years. While the GCPC data are generally under-estimates of both gauges, this is more evident in 1998 and 1999. The implications of using any of these data in a rainfall-runoff model are clear. Even if the gauge data are combined through an areal interpolation approach (kriging, for example) and the satellite data are scaled in some way to account for local re-calibration, there would still be substantial differences between the two rainfall inputs to the model.

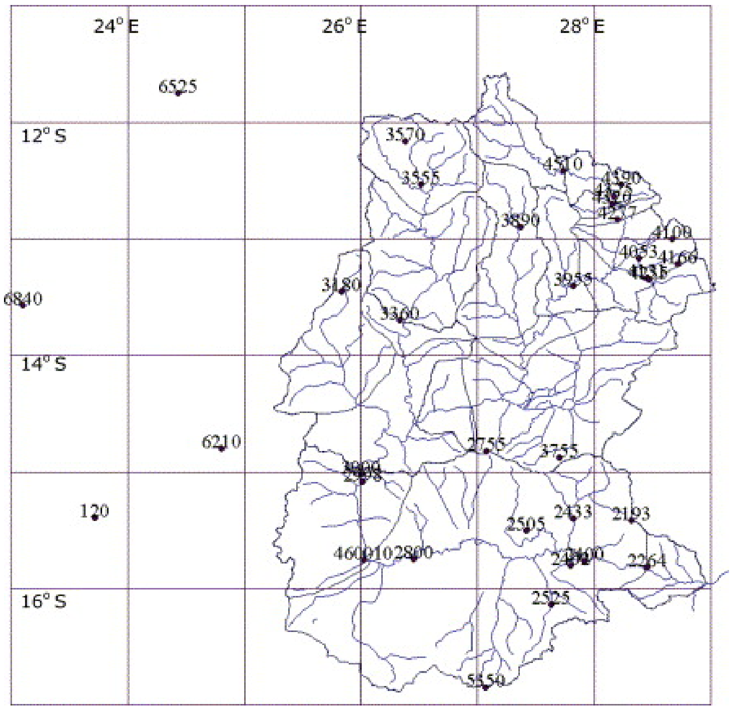

Figure 2. Kafue River basin showing raingauges and the channel network with a 1° × 1° grid overlay.

Table 1.

Results for the Kafue River basin, Zambia comparisons (with gauge data)

Gauge No.	MAP (mm)	Location	Gauge vs. GPCP		Gauge vs. PERSIANN		
			R^2	Slope	Grid No.	R^2	Slope
4375	1356	28.16E, 12.63S	0.84	0.63	3	0.82	0.97
4100	1162	28.67E, 13.00S	0.84	0.74	12	0.83	1.05
6210	947	24.80E, 14.80S	0.79	0.88	16	0.79	1.53
5350	859	27.07E, 16.85S	0.83	0.93	4	0.85	1.32

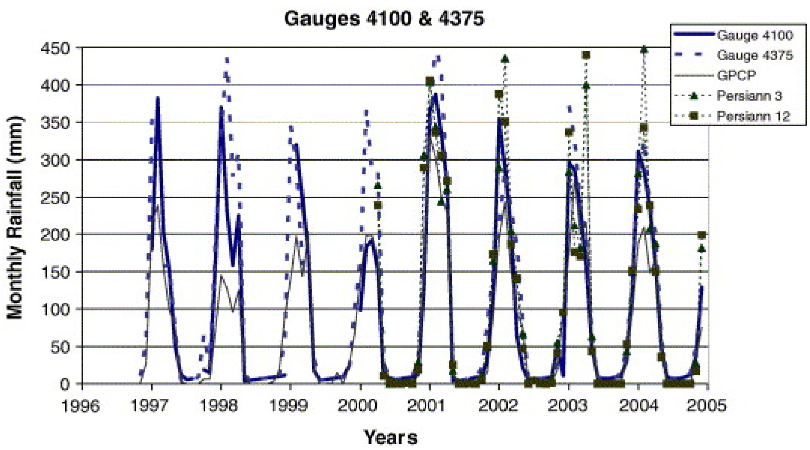

Figure 3. Time series comparisons for the data associated with the northern grid point in the Kafue River basin, Zambia.

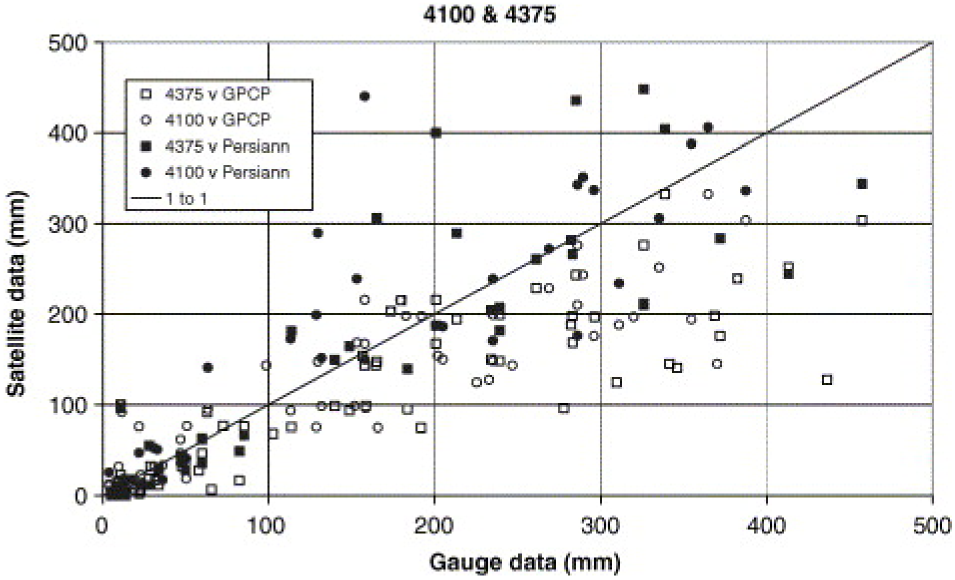

Figure 4. Scatterplot comparisons for the data associated with the northern grid point in the Kafue River basin, Zambia.

Further south, within the lower rainfall areas of the Kafue basin, the situation changes somewhat. The R^2 values remain relatively similar and there is very little distinction between the two satellite data sets. However, the MAP of the PERSIANN data remains high, such that there is a substantial systematic difference between these data and gauges 6210 and 5350 (Table 1 – note the regression slopes of 1.53 and 1.32). The GPCP data still tends to under-estimate rainfall at gauge 6210, but less so at gauge 5350. It is therefore clear that there is far less spatial variation in the satellite rainfall data than the gauge data, which is probably related to the resolution of the satellite data calibration process. The implication is that regional correction factors (see Thorne et al., 2001) would have to be applied to the satellite data to ensure that the gross rainfall depth (expressed through the MAP) conformed to the assumed 'real' spatial variation (based on gauged data).

Okavango River basin, Angola

A total of 8 1° grids cover the upper parts of the Okavango River basin (Fig. 5). Data for two grid squares (18.5E, 13.5S; 17.5E, 14.5S) were extracted from the GCPC database. There are no gauge rainfall data for this example as they all closed down during the early 1970s. However, Wilk et al. (2006) present an analysis of the satellite data that were used in the WERRD project compared to spatially averaged gauge data. The analysis was based on the use of the two data sets within a hydrological model. The model was calibrated using the 1960s and 1970s gauge (rainfall and flow) data and then applied with the satellite data for the 1990s period. The satellite rainfall data were found to be generally higher than the gauge data, despite the fact that all other evidence (particularly gauged flows in the lower part of the basin) suggests that the 1990s was a much drier period. On the basis of this observation a simple non-linear correction equation was applied to ensure that the frequency characteristics of the revised satellite data were closer to those of the historical gauge data. When the revised satellite data were used with the calibrated hydrological model the results were much improved (see Wilk et al., 2006 and Hughes et al., 2006, for further details). Table 2 and Figure 6 and Figure 7 therefore use the revised WERRD satellite data as the basis for comparison with the GPCP and PERSIANN satellite data. However, it should be clearly understood that the corrections applied to the WERRD satellite data were very simplistic and not intended to be the final solution to the problem.

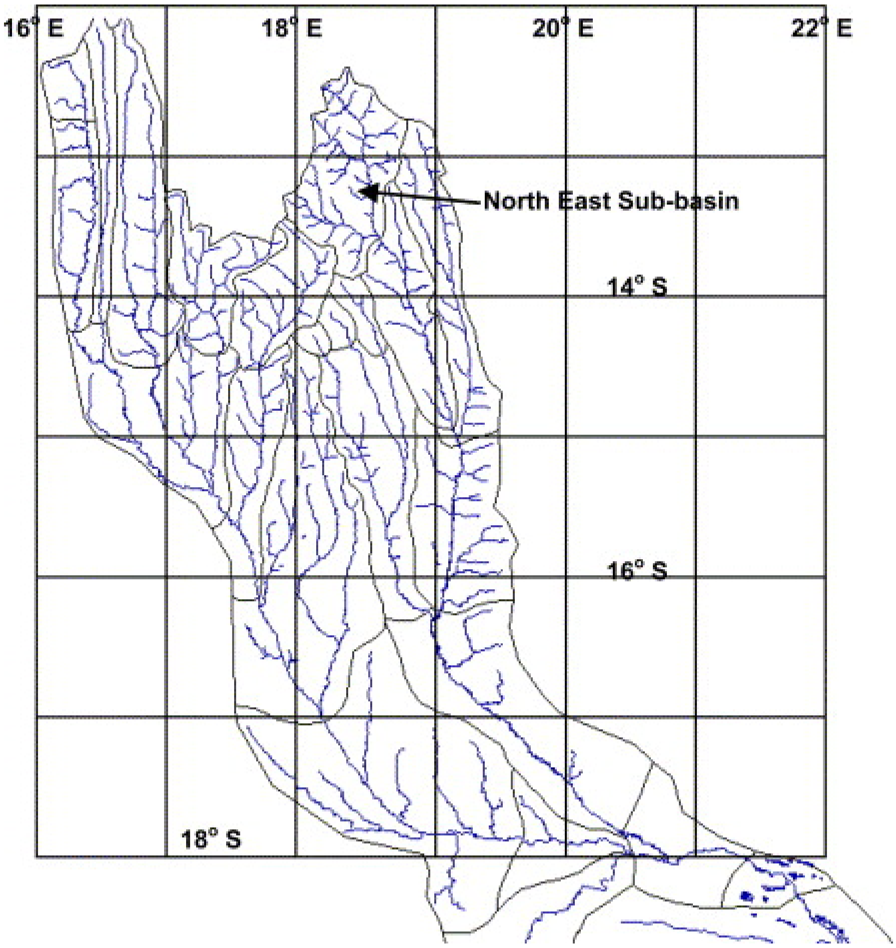

Figure 5. Okavango River basin showing sub-basins and the channel network with a 1° × 1° grid overlay.

Table 2.

Results for the Okavango River basin, Angola comparisons (with revised WERRD satellite data)

Sub basin	MAP (mm)	Revised WERRD vs. GPCP			Revised WERRD vs. PERSIANN		
		Grid point	R^2	Slope	Grid No.	R^2	Slope
North East	1120	18.5E, 13.5S	0.59	0.67	1–10	0.87	1.46
Cuelei	1207	17.5E, 14.5S	0.54	0.58	1, 2, 5, 6, 9 & 10	0.74	1.16

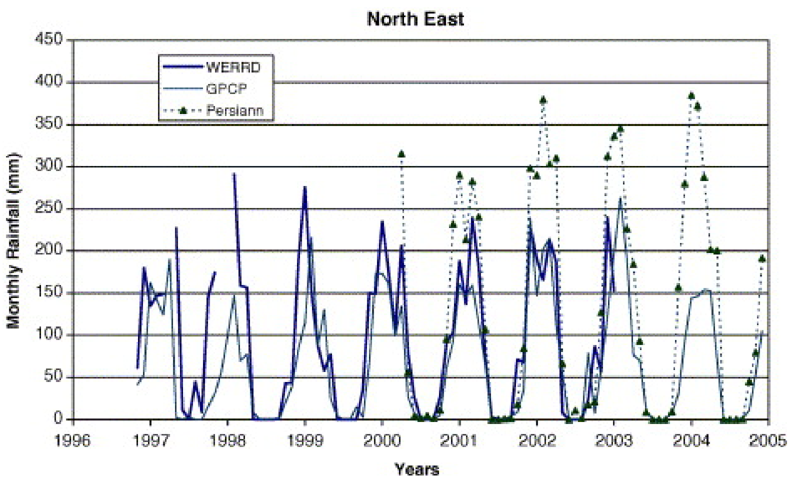

Figure 6. Time series comparisons for the data associated with the North East sub-basin in the Okavango River basin, Angola.

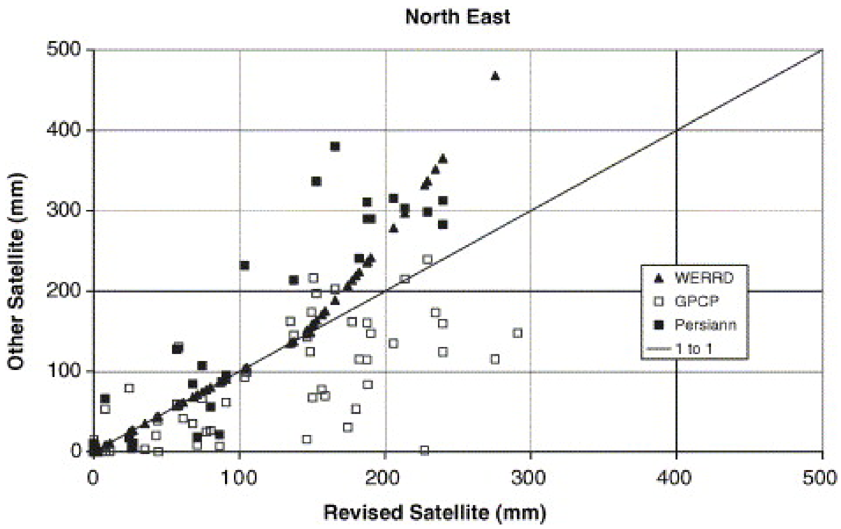

Figure 7. Scatterplot comparisons for the data associated with the North East sub-basin in the Okavango River basin, Angola.

The two 1° grid squares selected cover two of the sub-basins of the modelling distribution system used in the WERRD study (North East and Cuelei – see Hughes et al., 2006) and the PERSIANN data used are the mean values of all the 0.25° grid squares falling within the sub-basin areas (Table 2). Figure 6 and Figure 7 suggest that the overall relationship between the revised WERRD satellite and GPCP data is not very good, despite good correspondence in some years. As with the southern parts of the Kafue basin, the PERSIANN data appear to over-estimate the rainfall, however, there is a better correlation with the WERRD satellite data. It is difficult to draw any real conclusions about the comparisons at this stage of the study because of the lack of any gauged data for the satellite data periods. The comparisons have therefore simply identified the differences between the sources of data that will have to be further analysed before being used as input to a hydrological model.

Thukela River basin, South Africa

A total of 4 1° grids cover the majority of the Thukela River basin and the 30.5E, 28.5S point represents the lower part of the basin (Fig. 8). While there are some 50 gauges within the catchment with historical records, many of these are no longer operational and for the selected 1° grid there are only 4 gauges which have reasonably complete records for the period up to the middle of 2000. Fig. 9 illustrates the variations in monthly rainfall totals for the 4 gauges and the GPCP data, while Fig. 10 compares the satellite data sources (GPCP for the 1° grid and the 4 PERSIANN 0.25° grid squares corresponding to the location of the raingauges). Table 3 provides the statistics of comparison for the Thukela data and as there is very little overlap between the available gauge data and the PERSIANN data, the latter have been compared to the GPCP data.

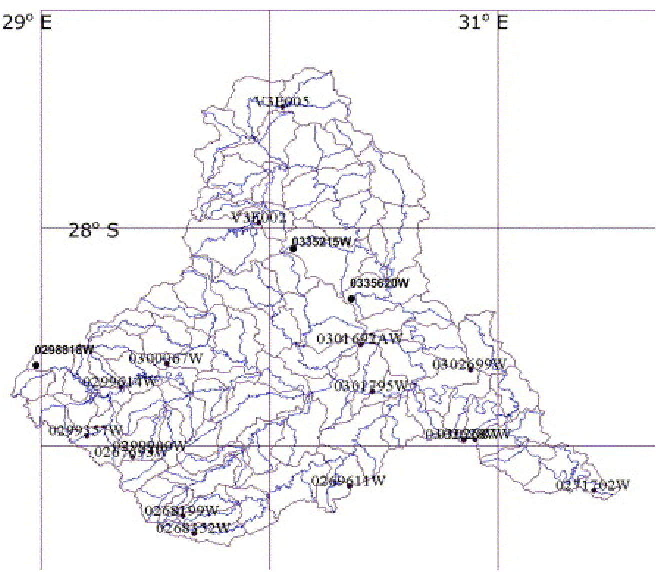

Figure 8. Thukela River basin showing raingauges and the channel network with a 1° × 1° grid overlay.

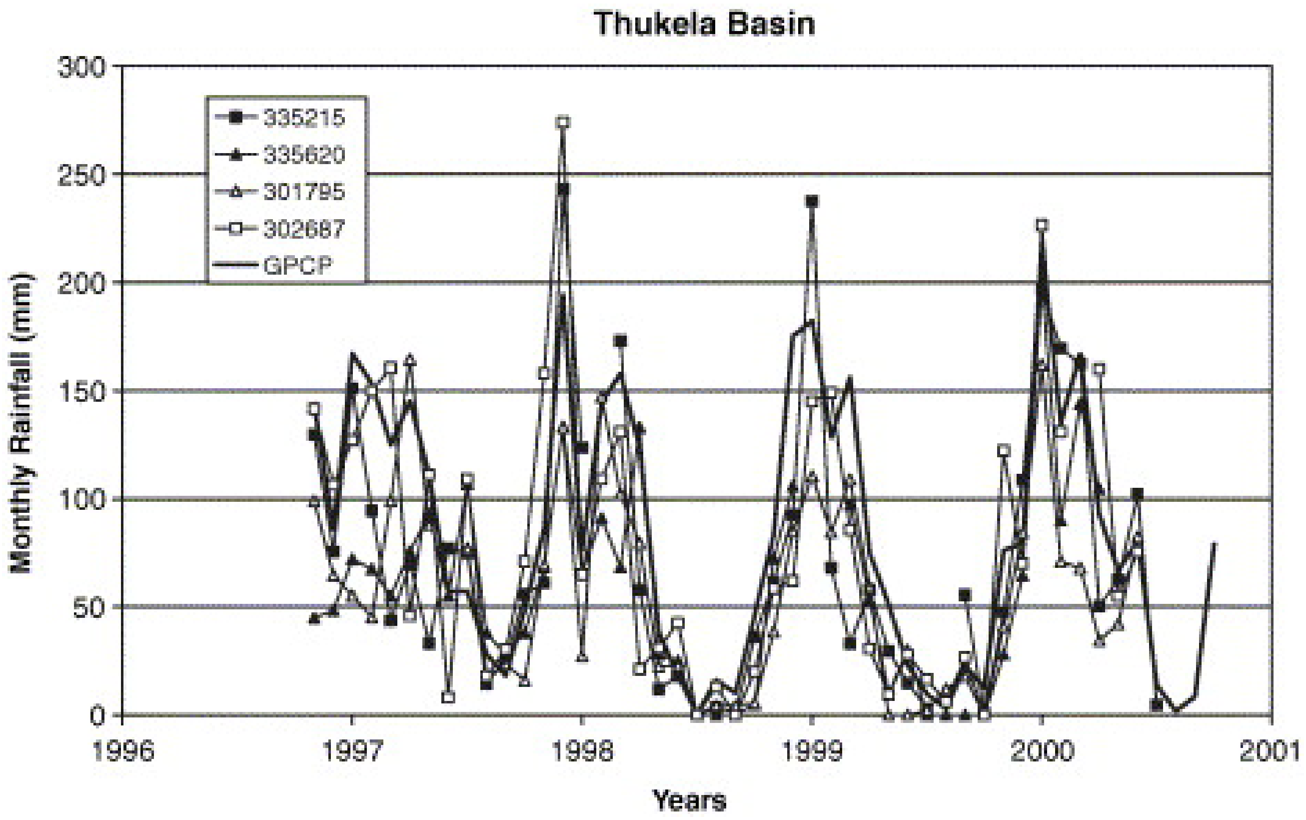

Figure 9. Time series comparisons for the gauge data associated with the Thukela River basin, South Africa.

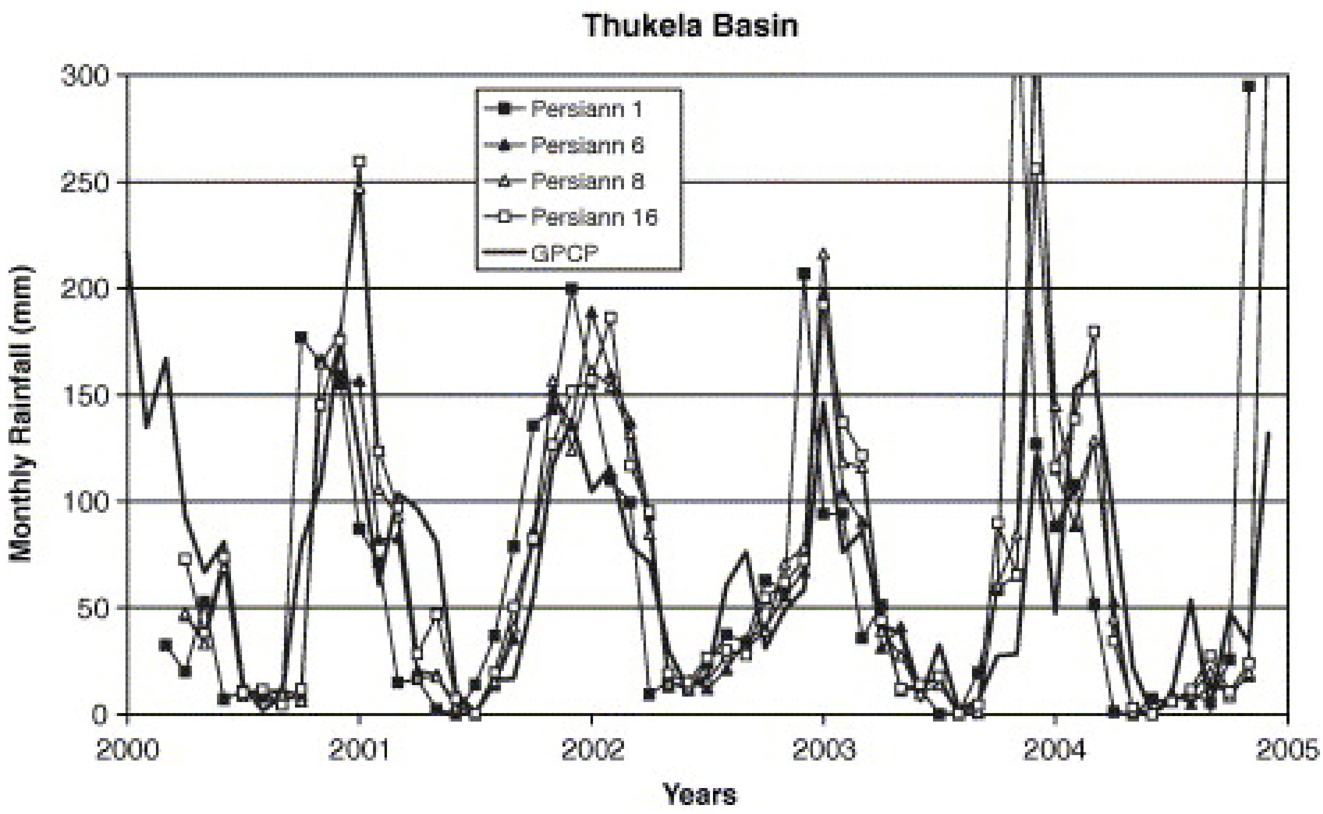

Figure 10. Time series comparisons for the satellite data associated with the Thukela River basin, South Africa.

Table 3.

Results for the Thukela River basin, South Africa comparisons

Gauge No.	MAP (mm)	Location	Gauge vs. GPCP		GPCP vs. PERSIANN		
			R^2	Slope	Grid No.	R^2	Slope
Using GPCP grid point 30.5E, 28.5S							
335215	874	30.13E, 28.08S	0.53	1.02	1	0.54	1.09
335620	703	30.37E, 28.35S	0.64	1.32	6	0.55	1.13
301795	680	30.45E, 28.75S	0.65	1.38	8	0.55	1.19
302687	949	30.90E, 28.97S	0.51	0.94	16	0.63	1.22
Using GPCP grid point 29.5E, 28.5S							
298818	1662	28.97E, 28.63S	0.39	0.46	3	0.53	1.03

Fig. 9 suggests that the GPCP data could represent a reasonable estimate of the basin average rainfall, with a tendency to over-estimate, if it is assumed that the 4 gauges are representative (see the slope values in Table 3). Fig. 10 and Table 3 suggest that (as with the previous examples) the PERSIANN rainfall estimates are even higher, with some extreme values compared to the GPCP data (2004, for example). There are substantial variations in monthly rainfall totals between the 4 PERSIANN grid point data. While the variations are lower than the variations between the 4 gauge points, this is to be expected as the PERSIANN data already represent some spatial averaging. It is not possible, at this stage, to assess whether these variations are a true reflection of reality, but this result is encouraging from the point of view of the possibility of simulating spatial variations in runoff response. Less encouraging are the results of the comparisons for a part of the basin within the high rainfall Drakensberg mountains to the west using gauge 298818 (Table 3 and Fig. 11). Both satellite data sources seriously under-estimate the rainfall for this part of the basin suggesting that the topographic controls on rainfall would need to be accounted for by further calibration and adjustment of the satellite data.

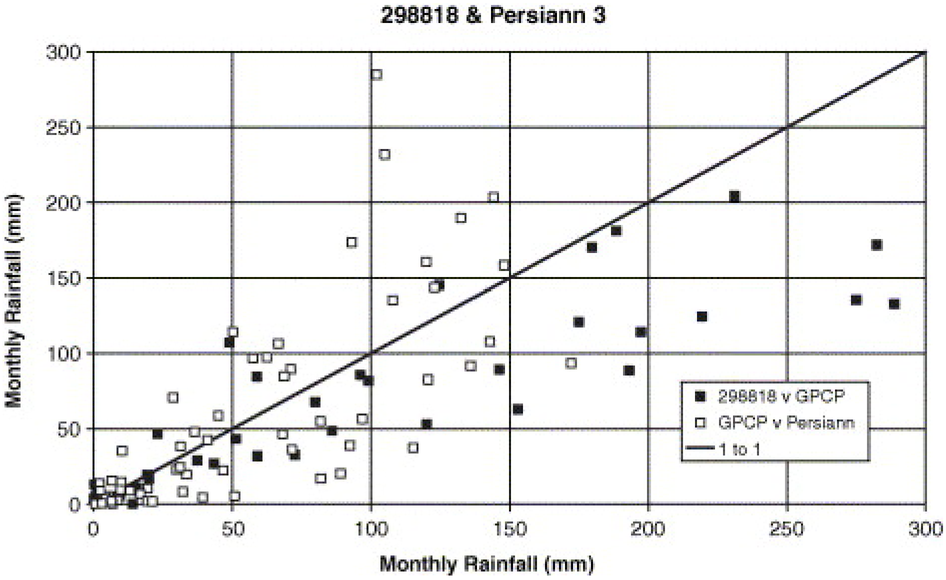

Figure 11. Scatterplot comparisons for a Drakensberg gauge within the Thukela River basin, South Africa (298818 data are on the *X*-axis for the solid symbols and GPCP on the *X*-axis for the open symbols).

Kat River basin, South Africa

This basin is smaller than would normally be considered appropriate for the application of the GPCP data, occupying less than 20% of a 1° grid square (Fig. 12) as well as experiencing substantial topographic influences on precipitation. Data (up to mid 2000) for five gauges are available, two (78226 and 78227) are in the lower rainfall, southern part of the basin, while three (78755, 100329 and 100508) are in the higher rainfall, elevated northern parts of the basin. Comparisons between gauges resulted in R^2 values mostly in the range 0.6–0.8, although gauge 100508 appears to have anomalous data. Table 4 and Fig. 13 suggest that, despite the relatively low R^2 values for the gauge vs. GPCP comparisons, the impression is that the satellite data represent the variations in rainfall input to the basin reasonably well. In contrast to the previous areas, the PERSIANN data are not generally higher in value than the GPCP data. As with the Thukela, the satellite data are not able to represent the spatial variations caused by topographic influences and some form of local calibration will be required. The lack of relationship between gauge 100508 and other gauges (as well as the GPCP data) emphasises the need to carefully check ground-based rainfall, as well as satellite data sources.

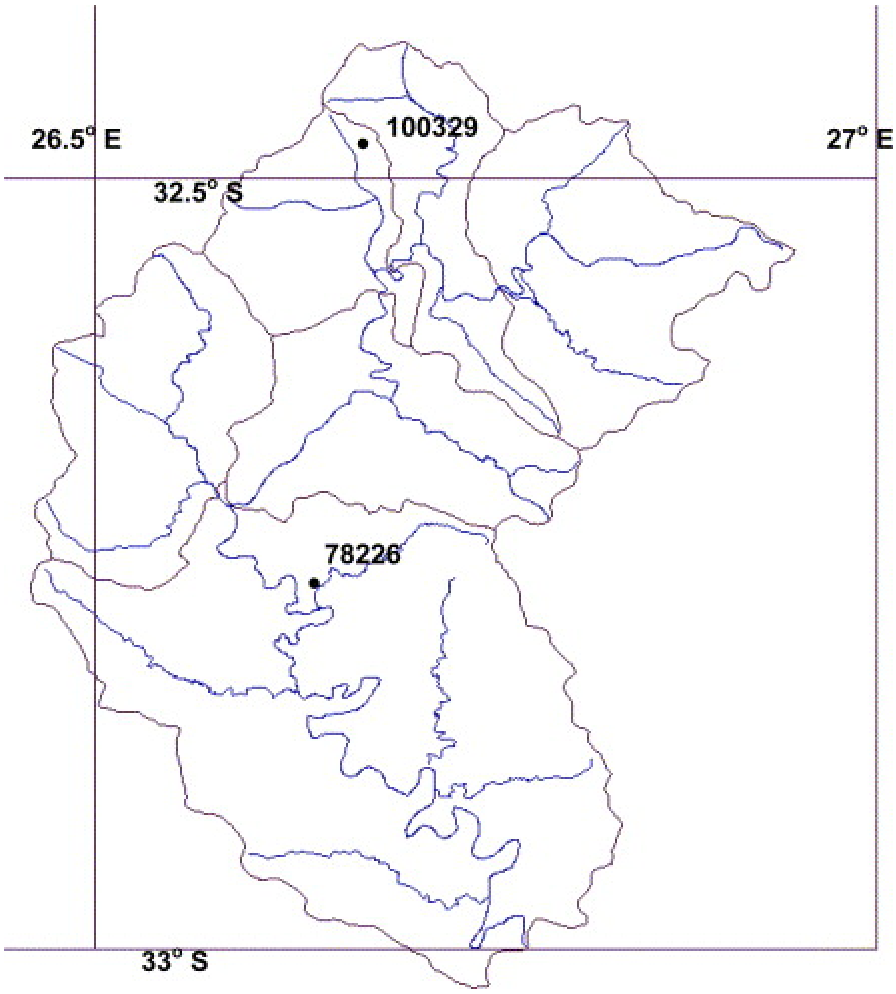

Figure 12. Kat River basin showing raingauges and the channel network with a 0.5° × 0.5° grid overlay.

Table 4.

Results for the Kat River basin, South Africa comparisons

Gauge No.	MAP (mm)	Location	Gauge vs. GPCP		GPCP vs. PERSIANN		
			R^2	Slope	Grid No.	R^2	Slope
78226	524	26.63E, 32.77S	0.61	1.13	12	0.48	0.62
78227	530	26.63E, 32.78S	0.54	1.16	12	0.48	0.62
78755	902	26.93E, 32.58S	0.64	0.66	15	0.52	0.81
100329	1005	26.68E, 32.48S	0.54	0.62	10	0.59	0.85
100508	822	26.78E, 32.47S	0.21	0.74	14	0.56	0.82

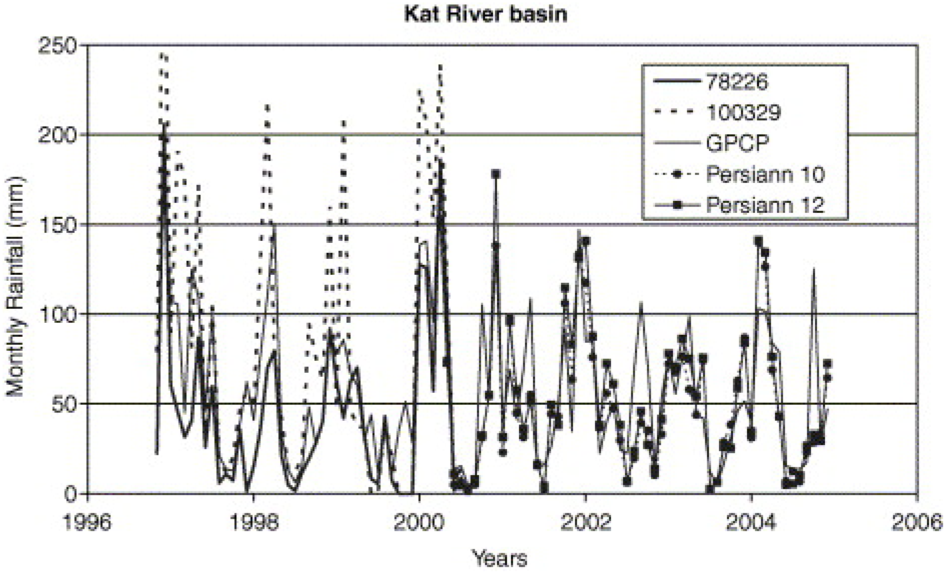

Figure 13. Time series comparisons for some of the data associated with the Kat River basin, South Africa.

Discussion and conclusions

It is important to recall that the objective of the comparisons is to assess whether the satellite data can be used in conjunction with gauge data as inputs to a hydrological model. In many cases, the model will have been calibrated using the gauge data and then applied with the satellite data to extend the length of simulated flow data. The calibrated parameters will inevitably reflect any errors or inadequacies (such as a lack of adequate spatial representation) in the gauge data, or the way in which the gauge data were used to obtain sub-basin average rainfall inputs. This latter point is really concerned with what is accepted as the 'true' rainfall data, when it is clearly understood that none of the available data sources can be considered as 'true'. There are two main reasons why the gauge data should be accepted as 'true' with respect to establishing the model calibrations. The first relates mainly to the Okavango example and is associated with the fact that the flow data for many of the sub-basins, against which the model is calibrated, does not extend into the period covered by the satellite rainfall data. There is therefore no possibility of calibrating the model in a large part of the basin against satellite data. The second reason is that these preliminary analyses have demonstrated that the satellite data are not sensitive to topographic influences on precipitation. While gauge data are commonly not adequate to completely quantify spatial variations due to topographic influences, the satellite data appear to ignore these completely.

There are a number of potential problems associated with the alternative approach of calibrating the model independently against both the gauge and satellite rainfall data. The first is that the satellite data are currently too short to represent the variability of rainfall-runoff responses that typically occur within southern Africa. The second is related to the type of model typically used in the region and the method of transferring model parameters to ungauged basins. Frequently, conceptual type models are used in which the main calibration parameters are expected to have at least some association with physical basin properties. Calibration is normally undertaken using manual fitting methods and parameter transfer to ungauged basins largely based on assumed differences in basin characteristics. Therefore, if the parameters are more a reflection of the rainfall inputs to the model, this approach becomes difficult to apply. In this context, the best approach would therefore seem to be to focus on processing the satellite rainfall data to try and match the characteristics of the historical gauge rainfall and to retain the parameters calibrated using the gauge data. This issue will be further pursued during the next phase of the study when the rainfall data will be used with the rainfall-runoff model.

The four study areas represent very different climate regimes within southern Africa and the preliminary results are encouraging enough to suggest that further detailed investigations are justified. The next step is to make decisions about whether, and how, the satellite data should be further processed so that they can be used in conjunction with the gauge data. The preliminary analysis suggests that they cannot be used without modifications. The real issue is therefore to determine if it is possible to develop 'effective' correction (local calibration) relationships that can be applied to the satellite data to ensure that they are compatible with the available gauge data and a calibrated rainfall-runoff model. The word ‘effective’ in this regard has yet to be properly defined, but must take into consideration the constraints referred to in the introduction with respect to the resources available to water resource practitioners in developing countries.

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